Energy Demand Response Modeling for High Performance Computing Systems

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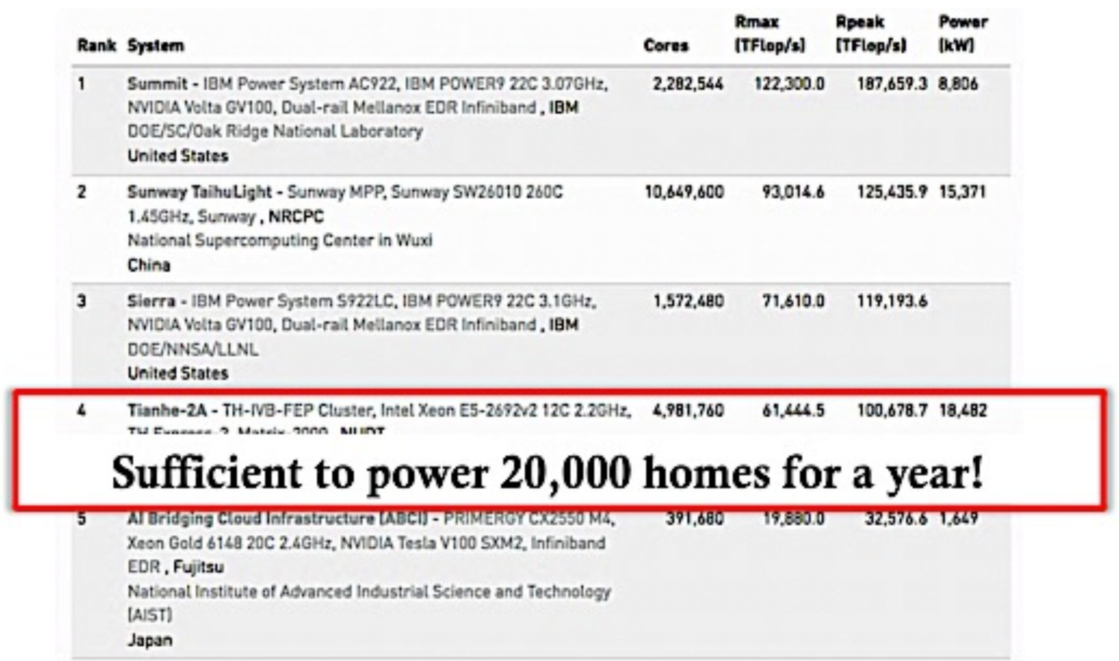
Motivation

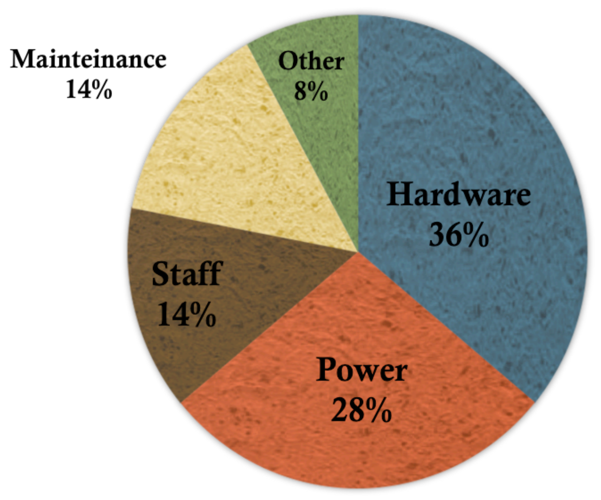
HPC systems are "power-hungry"
- China's 34-petaflop Tianhe-2 consumes 20MWs of power
- Future HPC systems may consume hundreds of megawatts of electricity



Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	Summit - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband, IBM DOE/SC/Oak Ridge National Laboratory United States	2,282,544	122,300.0	187,659.3	8,806
2	Sunway TaihuLight - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway, NRCPC National Supercomputing Center in Wuxi China	10,649,600	93,014.6	125,435.9	15,371
3	Sierra - IBM Power System S922LC, IBM POWER9 22C 3.1GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband, IBM DOE/NNSA/LLNL United States	1,572,480	71,610.0	119,193.6	
4	Tianhe-2A - TH-IVB-FEP Cluster, Intel Xeon E5-2692v2 12C 2.2GHz,	4,981,760	61,444.5	100,678.7	18,482
5	AI Bridging Cloud Infrastructure (ABCI) - PRIMERGY CX2550 M4, Xeon Gold 6148 20C 2.4GHz, NVIDIA Tesla V100 SXM2, Infiniband EDR, Fujitsu National Institute of Advanced Industrial Science and Technology (AIST) Japan	391,680	19,880.0	32,576.6	1,649

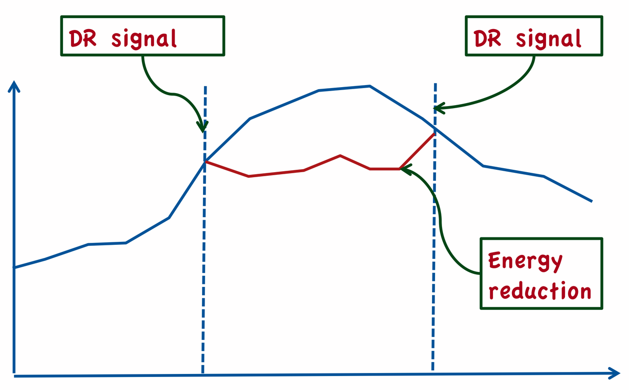
Sufficient to power 20,000 homes for a year!

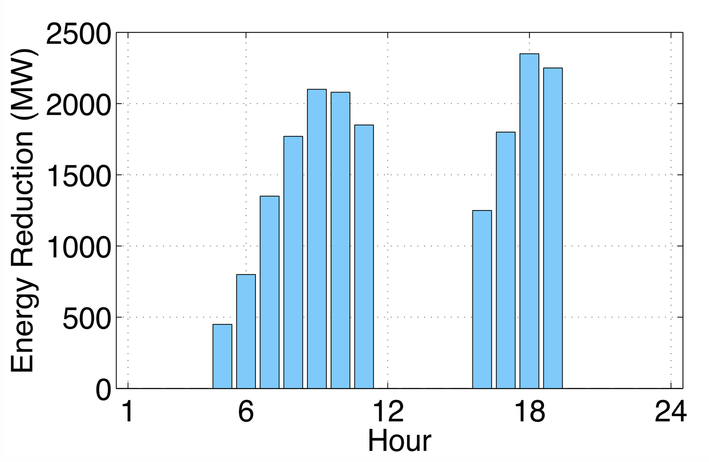
HPC systems are "energy-costly"
- Worldwide investment on supercomputers in 2016: $38 billion
- Supercomputer's lifelong energy cost almost equals investment cost
- Advent of Exascale: 20MW → $20 million/year for electricity



Demand Response

- Participants reduce energy consumption during emergency events or high electricity price period
- Emergency demand response: mandatory energy reduction to target level
- Economic demand response: voluntary participation based

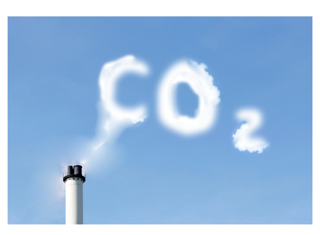




Energy reduction at PJM on January 7, 2014

Demand response is getting popular
- Many well-known companies (e.g., Google, Apple) already participating
- Participation in demand response to double in 2020

Financial benefits

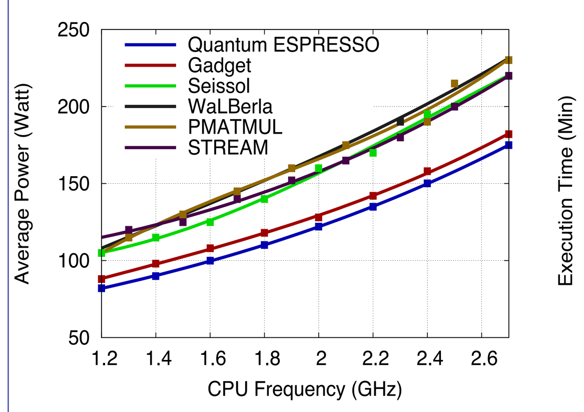


Environmental benefits

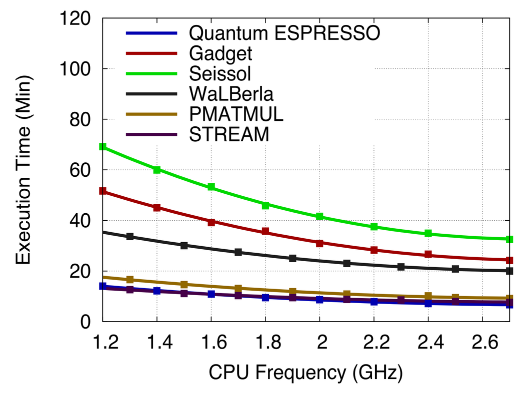
Grid Stability

HPC Emergency DR Model

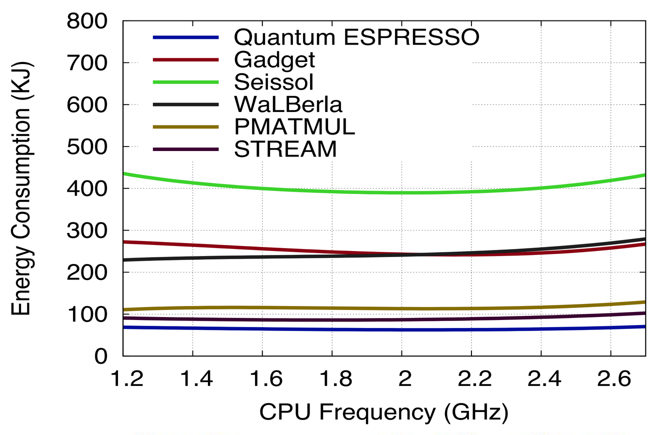
- Power/performance prediction model
  - Empirical data
  - Polynomial regression
- Demand response job scheduling
  - FCFS with possible job eviction
- Resource provisioning
  - DVFS [1], power-capping, node scaling [2]



$p(j,f) = a_j + b_j \cdot f + c_j \cdot f^2 + d_j \cdot f^3$



$t(j,f) = \alpha_j + \beta_j \cdot f + \gamma_j \cdot f^2$



$e(j,f) = n_j \cdot p(j,f) \cdot t(j,f)$

Job scheduling
- During normal operation
  - Traditional job scheduling
  - Optimized for best performance (max frequency)
- During demand response periods
  - Minimize energy for resource allocation
  - Reduce power limit

Resource allocation
- During normal operation
  - Run applications at maximum frequency for best performance
- During demand response: energy conservation
  - Run applications at optimum frequency

$$\text{Minimize: } \sum_{j \in R} e_R(j, f_j)$$

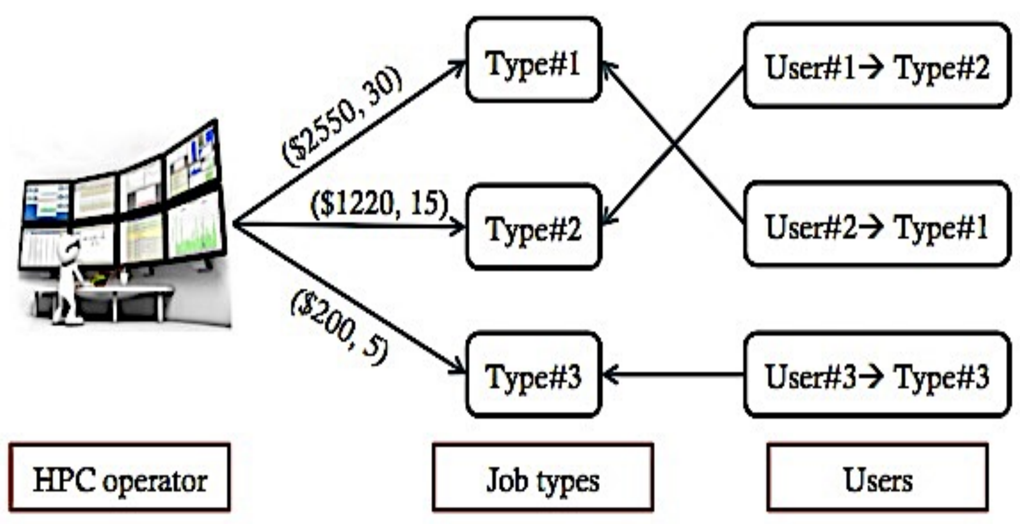
$$\text{subject to} \quad f_{min} \le f_j \le f_{max}$$

$$p_{run} = \sum_{j \in R} p(j, f_j) \le \hat{p}$$

$$\text{where, } \; e_R(j, f_j) = (1 - \alpha_j) \cdot n_j \cdot p(j, f_j) \cdot t(j, f_j)$$

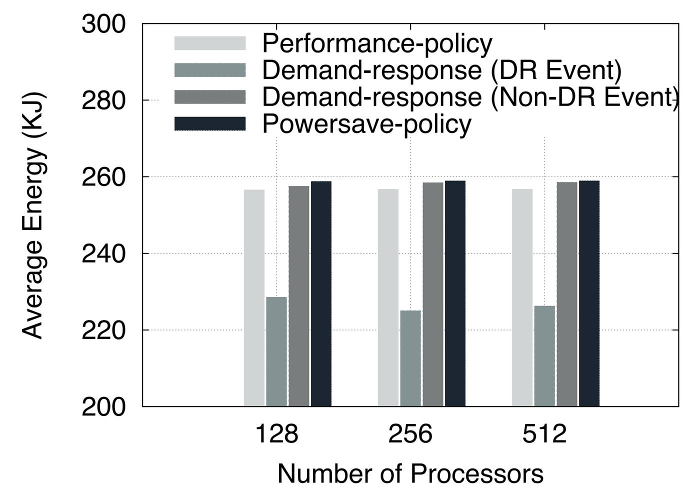
HPC Economic DR Model

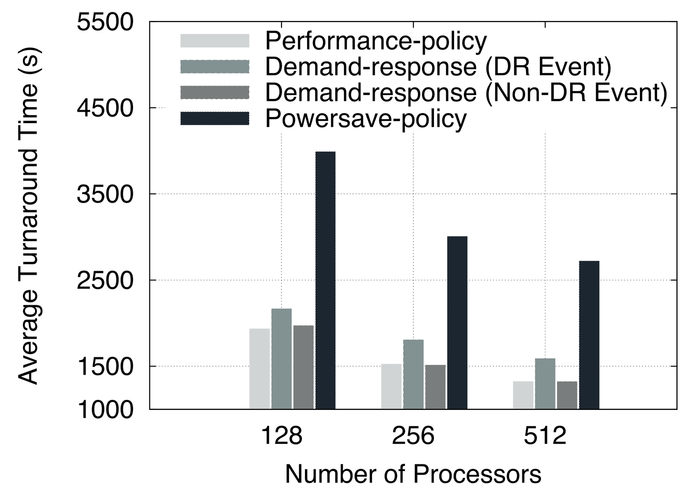
- How to incentivize HPC users for participation?
  - Participation may introduce execution delays
  - Need a proper rewarding mechanism
- A contract-based rewarding mechanism [3]
  - To incentivize HPC users' participation



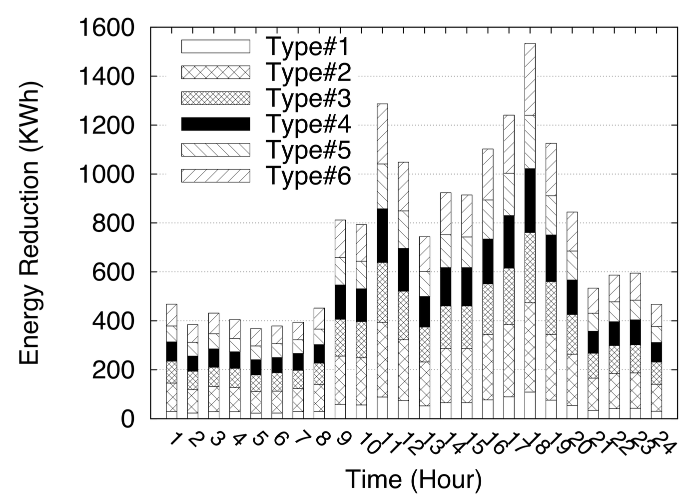
Evaluation

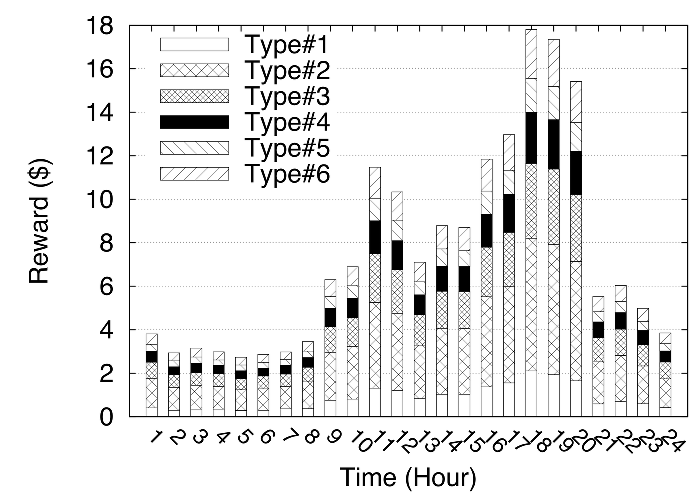
- Demand-response: optimal resource allocation
- Performance-policy: max frequency for best performance
- Powersave-policy: min frequency for least power consumption





Emergency DR: Reduced energy consumption at moderate runtime increase





Economic DR: Reduced energy consumption (as much as 10% some times), and various reward amount

Summary

- HPC demand-response models
  - Emergency DR participation
  - Economic DR participation
- A win-win-win situation to all:
  - HPC systems reduce energy cost
  - HPC users earn rewards
  - Power grid achieves energy reduction and power stability

References

[1] K.Ahmed,J.Liu,andX.Wu,"An energy efficient demand-response model for high performance computing systems," in IEEE MASCOTS 2017.
[2] K. Ahmed, J. Liu, and K. Yoshii, "Enabling demand response for hpc systems through power capping and node scaling," in IEEE HPCC 2018.
[3] K. Ahmed, J. Bull, and J. Liu, "Contract-based demand response model for hpc systems," Submitted for publication.